Tricuspid valve replacement provides better long-term survival and tricuspid valve function than repair in patients with systemic right ventricle

Akihisa Furuta, MD, PhD, Takeshi Shinkawa, MD, PhD, Satoshi Okugi, MD, Hisashi Yoshida, MD, and Hiroshi Niinami, MD, PhD

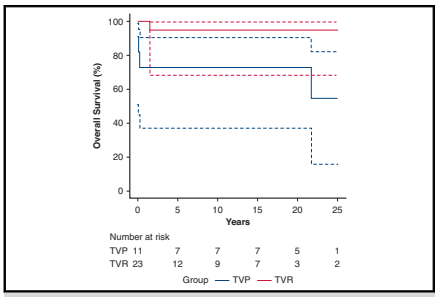
ABSTRACT

Objective: The purpose of this study is to compare the long-term outcomes of 2 different tricuspid surgeries including valvuloplasty and replacement for significant tricuspid regurgitation in patients with systemic right ventricle.

Method: This is a retrospective study of 34 patients with dextro-transposition of the great arteries or levo-transposition of the great arteries with biventricular circulation and systemic right ventricle undergoing tricuspid valve surgery between April 1979 and April 2022. Patients were divided into 2 groups based on the procedure: tricuspid valvuloplasty (n = 11) and tricuspid valve replacement (n = 23). These groups were compared in terms of survival, tricuspid valve dysfunction, and tricuspid valve–related reoperation.

Results: There was no significant difference between the groups in operative age, body weight, the proportion of dextro-transposition of the great arteries, Ebstein-like tricuspid dysplasia, and preoperative right ventricular volume/function. During the median follow-up of 9.7 years, there was 1 early death (tricuspid valvuloplasty group) and 4 late deaths (3 in tricuspid valvuloplasty group and 1 in tricuspid valve replacement group). There were 7 tricuspid valve dysfunctions, including 6 significant tricuspid regurgitations in the tricuspid valvuloplasty group and 1 prosthetic valve dysfunction in the tricuspid valve replacement group, and 4 tricuspid valve-related reoperations (3 in the tricuspid valvuloplasty group and 1 in the tricuspid valve replacement group) were performed. There were significant differences between the groups in survival (tricuspid valvuloplasty vs tricuspid valve replacement: 72.7 vs 94.7% at 10 years after surgery, $P = .0328$) and cumulative incidence of tricuspid valve dysfunction at 10 years after tricuspid surgery (tricuspid valvuloplasty vs tricuspid valve replacement: 27.3% vs 0%, $P = .0121$).

Conclusions: Tricuspid valve replacement provided better long-term survival and tricuspid function in patients with systemic right ventricle compared with tricuspid valvuloplasty. (JTCVS Open 2023;15:382-93)



TVR provided better long-term outcomes than valvuloplasty.

CENTRAL MESSAGE

TVR provided better long-term survival and tricuspid valve function in patients with systemic RV and biventricular circulation compared with TVP.

PERSPECTIVE

The favorable procedure for systemic TR remains unclear in patients with systemic RV and biventricular circulation. TVR will provide better long-term outcomes in terms of survival and tricuspid valve function. This will be applied to both l-TGA and d-TGA.

Patients with levo-transposition of the great arteries (l-TGA) without operative history or with a history of conventional repair and patients with dextro-transposition of the great arteries (d-TGA) with a history of atrial switch operation have the morphological right ventricle (RV) sustaining systemic circulation in biventricular circulation. Because of the exposure to systemic blood pressure and structural problem of the tricuspid valve, some patients will develop tricuspid regurgitation (TR) and require tricuspid valve surgery for significant TR.[1-5] Tricuspid valve surgery was generally divided into 2 types: tricuspid valvuloplasty (TVP) and tricuspid valve replacement

From the Department of Cardiovascular Surgery, The Heart Institute of Japan, Tokyo Women's Medical University, Tokyo, Japan.

Ethics approval: Tokyo Women's Medical University Institutional Review Board, Number 22 to 0563.

Read at the 103rd Annual Meeting of The American Association for Thoracic Surgery, Los Angeles, California, May 6-9, 2023.

Received for publication March 29, 2023; revisions received May 16, 2023; accepted for publication June 20, 2023; available ahead of print July 25, 2023.

Address for reprints: Takeshi Shinkawa, MD, PhD, Department of Cardiovascular Surgery, Tokyo Women's Medical University, The Heart Institute of Japan, 8-1, Kawadacho, Shinjuku-ku, Tokyo 162-8666, Japan (E-mail: shinkawa.takeshi@twmu.ac.jp).

2666-2736

https://doi.org/10.1016/j.xjon.2023.06.013

Abbreviations and Acronyms

d-TGA = dextro-transposition of the great arteries
l-TGA = levo-transposition of the great arteries
RV = right ventricle
TR = tricuspid regurgitation
TVP = tricuspid valvuloplasty
TVR = tricuspid valve replacement

(TVR); however, the optimal procedure remains unclear in patients with the systemic RV because of the small number of patients.

This study aims to assess the long-term outcomes of tricuspid valve surgery for patients with systemic RV and clarify the clinical differences between TVP and TVR.

PATIENTS AND METHODS

Patient Population and Study Design

This study is a retrospective cohort study of consecutive patients who were diagnosed with l-TGA or d-TGA with biventricular circulation and systemic RV and underwent TVP or TVR for significant TR at the Tokyo Women's Medical University Hospital between April 1979 and April 2022. A total of 34 patients were enrolled and divided into 2 groups based on the procedure: TVP (n = 11) and TVR (n = 23). Medical records were reviewed, and basic demographic, intraoperative, and postoperative data were analyzed. These groups were compared in terms of survival, tricuspid dysfunction, tricuspid valve–related reoperation, and the size and function of the RV.

This study was approved and monitored by the Tokyo Women's Medical University's research ethics committee (Institutional Review Board Number: 22-0563, November 25, 2022). The need for patient consent was waived because of the retrospective, registry-based study design. This study was performed in conformity with the Declaration of Helsinki.

Evaluation and Definition

Preoperative and postoperative diameter, volume, and function of RV were assessed by transthoracic echocardiography or angiography. RV end-diastolic volume in angiography was expressed as percentage of the normal value based on the normal value,[6] and RV function was evaluated by fractional shortening and fractional area change. Tricuspid valve dysfunction was defined as significant TR (more than moderate) or prosthetic valve dysfunction including prosthetic valve stenosis (inflow >2 m/s) or more than a moderate paravalvular leak. Early mortality was defined as death within 30 days of tricuspid valve surgery regardless of discharge or death in the same admission. Late mortality was defined as any death after discharge.

The primary end point of this study was the group difference in long-term survival, and the secondary end point was the group difference in long-term tricuspid valve dysfunction.

Operative Indication and Procedure

Tricuspid surgery was performed under general anesthesia with transesophageal echocardiography support. Cardiopulmonary bypass was established with ascending aorta perfusion and bicaval or right atrium drainage. Intermittent cold crystalloid cardioplegia was administered after aortic crossclamping. Hypothermic perfusion was occasionally introduced based on the patient's status. The choice between TVP and TVR depended on the anatomic conditions and the surgeons' decision. TVP included resection/plication, artificial chordae tendineae technique, and annuloplasty such as the Kay-Reed technique or ring annuloplasty using a complete ring. The type of prosthetic valve was decided after consultation with the patient. A concomitant procedure was added based on the hemodynamics, and the epicardial pacemaker system was placed as necessary. For patients with mechanical valves, the postoperative anticoagulation goal was set for international normalized ratio of 2.0 to 2.5 with oral coumadin.

Statistical Analysis

All statistical analyses were performed with JMP Pro version 16 software (SAS Institute Inc) and EZR version 1.61 (Jichi Medical University). Data of continuous variables were presented as mean ± standard deviation for normal distribution and as median (25th–75th percentile interval) for non-normal distribution after confirming by the Shapiro–Wilk test. Categorical variables were presented as a number (proportion). A statistical significance in the analysis of contingency tables was assessed by the Fisher exact test. The normally distributed and non-normally distributed continuous variables between the groups were assessed by the Student *t* test and the Mann–Whitney *U* test, respectively. The actual survival time was estimated from the date of tricuspid valve surgery to the date of all-cause death or the last contact. Actuarial survivals were analyzed by the Kaplan–Meier curve, and a group comparison was conducted by the log-rank test. The competing risks regression model was developed to describe the cumulative incidence function according to the method of Fine and Gray. The cumulative incidence of tricuspid valve dysfunction and tricuspid-related reoperation was calculated with death as competing for failure events.

RESULTS

Patient Characteristics

Thirty-four patients were enrolled. There were 11 patients in the TVP group and 23 patients in the TVR group. The TVP group included 3 d-TGA and 8 L-TGA patients, and 5 L-TGA patients did not have a surgical history. The TVR group included 6 d-TGA and 17 L-TGA patients, and 12 L-TGA patients did not have a surgical history. The mean age was 20.7 ± 16.8 years (range, 1-50 years) in the TVP group and 26.8 ± 13.4 years (range, 3-51 years) in the TVR group with no significant differences ($P = .8662$). The proportion of the young patients aged less than 15 years was also similar (5/11 in TVP and 7 in TVP, $P = .4382$). There were no significant differences between the groups (TVP vs TVR) in body weight (37.6 ± 17.3 kg vs 50.9 ± 17.0 kg, $P = .0637$), time from the functional repair (14.8 [7.3-22.6] years vs 23.8 [11.7-35.3] years, $P = .3361$), and comorbidities. Dyslipidemia and chronic renal failure (creatinine > 2 mg/dL) were not found in both groups. Seven patients (1 in the TVP group and 6 in the TVR group) had a history of pacemaker implantation for sick sinus syndrome or atrioventricular block. Previous atrial switch operations in 9 patients with d-TGA were 6 Senning and 3 Mustard operations.

Preoperative echocardiography showed that almost all patients (97%: 33/34) had more than moderate TR. The most frequent reason for TR was abnormal cusp or chordae in the TVP group and annular dilatation in the TVR group. Preoperative catheter studies demonstrated that end-diastolic volume (121 [106-167] vs 133 [121-153] percent

of normal, $P = .5256$) and ejection fraction (51.6% ± 7.4% vs 47.6% ± 7.4%, $P = .2401$) of RV and cardiac index volume (2.9 ± 0.7 vs 2.8 ± 0.5, $P = .6159$) were not significantly different between groups. Patient characteristics are summarized in Table 1, and the surgical intervention flow chart is shown in Figure 1.

Operative and In-Hospital Outcomes

In the TVP group, valvuloplasty included annuloplasty in 7 patients, including the Kay-Reed technique in 5 and ring annuloplasty in 2, resection/plication in 4, and artificial chordae tendineae technique in 1. The size of the ring was 30 mm in 2 cases. In the TVR group, mechanical prostheses with a mean size of 29.9 ± 2.6 mm (range, 26-33 mm) were used in 21 patients, and bioprosthetic valves were used in 2 patients (29 mm and 31 mm).

A total of 36 concomitant procedures except for pacemaker or implantable cardiac defibrillator–related procedures were performed in 23 patients, and the most frequent concomitant procedure was surgical ablation. Pacemaker and cardiac resynchronization therapy devices were newly implanted in 4 patients (1 in the TVP group and 3 in the TVR group) and 2 patients (TVR group), respectively. Cardiopulmonary bypass time was not significantly different between the groups (TVP vs TVR: 127.9 ± 41.3 minutes vs 150.0 ± 71.0 minutes, $P = .3544$), whereas aortic crossclamp time was significantly longer in the TVR group than in the TVP group (67.4 ± 35.2 minutes vs 103.4 ± 49.5 minutes, $P = .0421$). Operative results are summarized in Table 2.

There was 1 early mortality in the TVP group. A 1-year-old boy, who was diagnosed with d-TGA and underwent the atrial switch operation (the Senning operation) at the age of 9 months, underwent TVP; however, he died of bleeding on the first postoperative day. In-hospital complications were 3 arrhythmia-related events (2 in the TVP group and 1 in the TVR group) and 2 surgery-related bleeding events only in the TVR group. The mean length of intensive care unit stay in was 4.0 (3.3-5.8) days in the TVP group and 3.0 (2.3-4.8) days in the TVR group ($P = .698$), and the mean length of hospital stay was 20.5 (15.8-35.3) days in the TVP group and 20.0 (14.0-24.0) days in the TVR group ($P = .5864$).

TABLE 1. Patient characteristics

Variable	TVP group	TVR group	*P* value
Patient number, n	11	23	
Age (y)	20.7 ± 16.8	26.8 ± 13.4	.8662
Male, n (%)	5 (45%)	15 (65%)	.4575
Body weight (kg)	37.6 ± 17.3	50.9 ± 17.0	.0637
Primary disease			
d-TGA, n (%)	3 (27%)	6 (26%)	1.0000
l-TGA, n (%)	8 (73%)	17 (74%)	1.0000
Without a history of cardiac surgery	5 (45%)	12 (52%)	1.0000
Time from the functional repair (y)	14.8 (7.3-22.6)	23.8 (11.7-35.3)	.3361
Comorbidity			
Hypertension	2 (18%)	6 (26%)	1.0000
Hyperuricemia	1 (9%)	2 (9%)	1.0000
Cerebrovascular disease	1 (9%)	0 (0%)	.3235
Arrhythmia	5 (45%)	13 (57%)	.7166
Advanced or complete atrioventricular block	2 (18%)	6 (26%)	1.0000
Atrioventricular nodal reentrant tachycardia	1 (9%)	3 (13%)	1.0000
Atrial fibrillation	1 (9%)	3 (13%)	1.0000
Sick sinus syndrome	1 (9%)	1 (4%)	1.0000
Ebstein-like tricuspid dysplasia	1 (9%)	4 (17%)	1.0000
Tricuspid valve regurgitation			
Mild-moderate	1 (9%)	0 (0%)	.3235
Moderate	4 (36%)	9 (39%)	1.0000
Severe	6 (55%)	14 (61%)	1.0000
Preoperative catheter study			
Right ventricular end-diastolic volume (% of normal)	121 (106-167)	133 (121-153)	.5256
Right ventricular ejection fraction (%)	51.6 ± 7.4	47.6 ± 7.4	.2401
Cardiac index (L/min/m^2)	2.9 ± 0.7	2.8 ± 0.5	.6159

TVP, Tricuspid valvuloplasty; *TVR*, tricuspid valve replacement; *d-TGA*, dextro-transposition of the great arteries; *l-TGA*, levo-transposition of the great arteries.

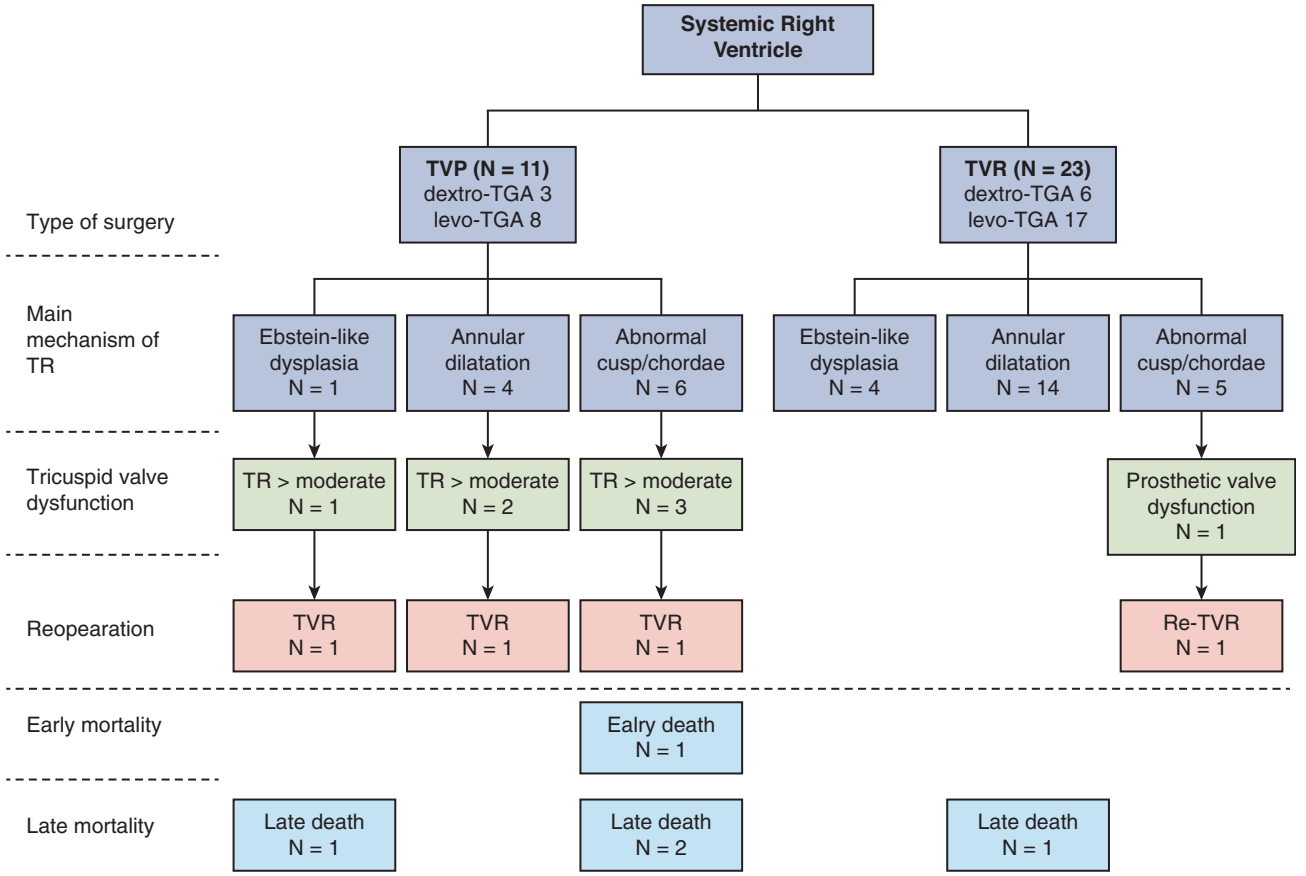


FIGURE 1. Surgical intervention flow chart. The proportion of d-TGA and l-TGA patients was similar in both groups. The most frequent reason for TR was abnormal cusp or chordae in the TVP group and annular dilatation in the TVR group. Tricuspid valve–related reoperations were performed in 4 patients. There was 1 early mortality and 4 late mortalities in this study. *TVP*, Tricuspid valvuloplasty; *TVR*, tricuspid valve replacement; *TGA*, transposition of the great arteries; *TR*, tricuspid regurgitation.

Late Outcomes

During the median follow-up of 9.6 (2.1-20.0) years, 29 patients were alive and 5 patients died. There were 4 late mortalities (3 in the TVP group and 1 in the TVR group). The causes of late mortalities in the TVP group were 2 heart failures and 1 pneumonia. A 50-year-old woman without a surgical history was diagnosed with l-TGA and significant TR due to abnormal cusp and underwent TVP. She experienced recurrent TR 20 years after TVP and finally died of RV failure. A 1-year-old boy was diagnosed with l-TGA and severe TR due to Ebstein-like dysplasia and underwent TVP with ventricular septal defect closure. He underwent TVR 1 month after TVP for recurrent TR causing severe heart failure; however, he died of heart failure 1 month after redo surgery. On the other hand, in the TVR group, a 2-year-old boy with a history of the Senning operation at 6 months of age for d-TGA underwent TVR using a mechanical valve. However, he died of sudden death 2 years after TVR. The overall survival at 10 years after tricuspid surgery was 72.7% ± 13.4% in the TVP group and 94.7% ± 5.1% in the TVR group (20 years, 72.7% ± 13.4% in the TVP group and 94.7% ± 5.1% in the TVR group; 25 years, 54.6% ± 18.7% in the TVP group and 94.7% ± 5.1% in the TVR group), and there were significant differences between the groups ($P = .0328$, Figure 2, *A*).

There were 7 tricuspid valve dysfunctions including 6 significant TRs in the TVP group and 1 prosthetic valve dysfunction in the TVR group. The cumulative incidences of tricuspid valve dysfunction at 10 years after tricuspid surgery was 27.3% in the TVP group and 0% in the TVR group (20 years, 38.2% in the TVP group and 18.9% in the TVR group), and there were significant differences between the groups ($P = .0121$, Figure 2, *B*).

Of 7 patients with tricuspid valve dysfunction, 4 underwent tricuspid valve-related reoperations; 3 patients in the TVP group underwent TVR for recurrent TR (1 month, 8 months, and 22 years after the TVP), and 1 patient in the TVR group underwent redo TVR concomitant with mitral valvuloplasty and the Cox-Maze procedure due to a severe pannus formation 18 years after the first TVR. The cumulative incidence of tricuspid valve–related reoperation at 10 years after tricuspid surgery was 18.2% in the TVP

TABLE 2. Operative results

Variable	TVP group	TVR group	*P* value
Cardiopulmonary bypass time (min)	127.9 ± 41.3	150.0 ± 71.0	.3544
Aortic crossclamp time (min)	67.4 ± 35.2	103.4 ± 49.5	.0421
Concomitant procedure, n (%)	9 (82%)	14 (61%)	.2714
Surgical ablation	2 (18%)	5 (22%)	1.0000
Atrial septal defect/patent foramen ovale closure	3 (27%)	3 (13%)	.3627
Pulmonary surgery	3 (27%)	2 (9%)	.2999
Mitral surgery	3 (27%)	1 (4%)	.0889
Ventricular septal defect closure	3 (27%)	1 (4%)	.0889
Left ventricle-pulmonary artery conduit replacement	0 (0%)	4 (17%)	.2799
Pulmonary artery plasty	1 (9%)	0 (0%)	.3235
Others	3 (27%)	2 (9%)	.2999
Early mortality, n	1 (9%)	0 (0%)	.3235
Late mortality, n	3 (27%)	1 (4%)	.0889

TVP, Tricuspid valvuloplasty; *TVR*, tricuspid valve replacement.

group and 0% in the TVR group (20 years, 18.2% in the TVP group and 18.9% in the TVR group), and there were no significant differences between the groups ($P = .1290$, Figure 2, *C*). Although there were 4 new cardiac resynchronization therapy device implantations (1 in the TVP and 3 in the TVR group), there was no new pacemaker implantation for atrioventricular block or sick sinus syndrome. In the TVR group, 1 patient with a history of atrial fibrillation experienced cerebral infarction 17 days after TVR using mechanical valve. There was no late bleeding or thrombotic events related to anticoagulant therapy.

The latest echocardiography data were obtained from 7 patients in TVP group and 22 patients in TVR group. Among 7 patients in the TVP group, 3 had tricuspid valve-related reoperations and 3 had more than moderate TR at the latest echocardiography. There were no significant differences between groups (TVP vs TVR) in end-diastolic diameter (52.0 [48.0-56.0] mm vs 52.5 [45.0-59.8] mm, $P = .8813$), end-systolic diameter (42.0 [36.0-43.0] mm vs 41.0 [37.0-47.0] mm, $P = .6104$), fractional shortening (0.21 [0.20-0.24] vs 0.22 [0.16-0.25], $P = .6490$), and fractional area change (27.0% [23.9-27.1] vs 22.2% [19.8-30.3], $P = .9263$) of the systemic RV.

Comparison of Dextro-Transposition of the Great Arteries and Levo-Transposition of the Great Arteries

There were 9 patients with d-TGA and 25 patients with L-TGA. There were no significant differences between the groups in age, body weight, comorbidities, the proportion of male patients, Ebstein-like tricuspid dysplasia, more than moderate TR, end-diastolic volume of the RV, and cardiac index, whereas significant differences were found in the number of patients without a cardiac surgical history and ejection fraction of the RV ($P = .009$, Table E1). Aortic crossclamp (d-TGA vs l-TGA: 86 [68-126] vs 94 [51 vs 128], $P = .9133$) and cardiopulmonary bypass (124 [78-154] vs 138 [113-222], $P = .2961$) times were similar in both groups.

The overall survival at 10 years after tricuspid surgery was 76.2% ± 14.8% in the d-TGA group and 92.0% ± 5.4% in the l-TGA group, and there were no significant differences between the groups ($P = .3107$, Figure 3). The cumulative incidence of tricuspid dysfunction at 10 years after tricuspid surgery was 11.1% in the d-TGA group and 8.0% in the l-TGA group, and there were no significant differences between the groups ($P = .7650$, Figure E1). The cumulative incidence of tricuspid valve-related reoperation at 10 years after tricuspid surgery was 11.1% in the d-TGA group and 4.0% in the l-TGA group, and there were no significant differences between the groups ($P = .6346$, Figure E1, *B*). The latest echocardiography revealed that end-diastolic diameter (d-TGA vs l-TGA: 40.5 ± 6.1 mm vs 55.3 ± 6.9 mm, $P = .0001$) and end-systolic diameter (32.9 ± 5.5 mm vs 43.8 ± 6.9 mm, $P = .0044$) of the systemic RV were significantly larger in the l-TGA group in the d-TG group, whereas fractional shortening (0.22 ± 0.04 vs 0.21 ± 0.06, $P = .7411$) and fractional area change (29.3 ± 9.2% vs 22.0 ± 6.8%, $P = .1459$) of the RV were comparable between the group.

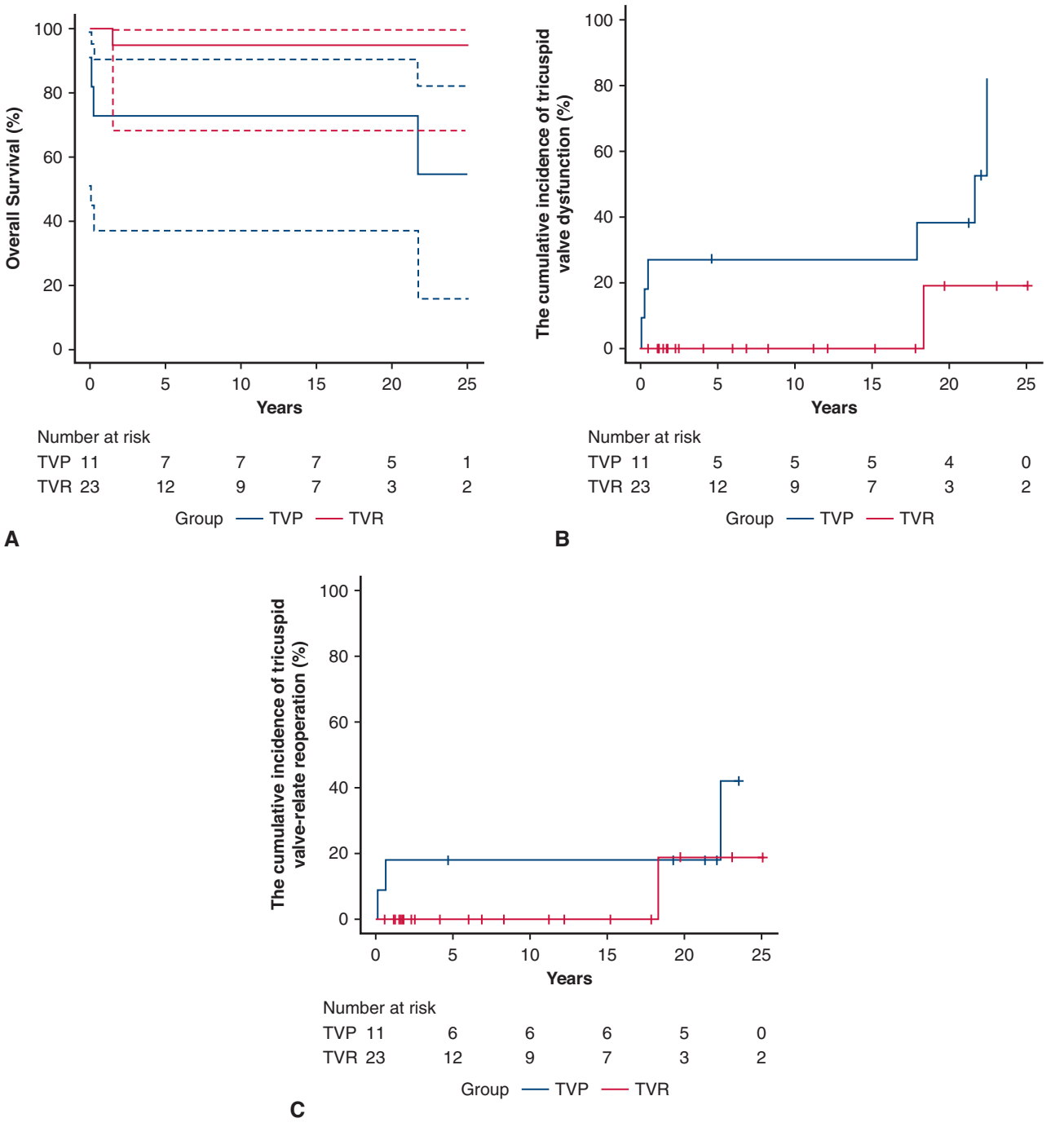


FIGURE 2. Comparison of TVP and TVR. Comparison of TVP (*blue line*) and TVR (*red line*) showing overall survival (A), cumulative incidence of tricuspid valve dysfunction (B), and cumulative incidence of tricuspid valve-related reoperation (C). A, The overall survival was 72.7% ± 13.4% (95% CI, 37.1%-90.3%) at 10 to 20 years after tricuspid surgery and 54.6% ± 18.7% (95% CI, 16.0%-81.9%) at 25 years in the TVP group, whereas that was 94.7% ± 5.1% (95% CI, 68.1%-99.2%) at 10 to 25 years in the TVR group ($P = .0285$). B, The cumulative incidence of tricuspid valve dysfunction was 27.3% (95% CI, 6.5%-53.9%) at 10 years after tricuspid surgery, 38.2% (95% CI, 11.5%-65.2%) at 20 years, and 52.7% (95% CI, 18.1%-78.7%) at 22 years in the TVP group, whereas that was 0% at 10 to 15 years and 18.9% (95% CI, 0.8%-56.1%) at 20 years in the TVR group. There were significant differences between the groups ($P = .0121$). C, The cumulative incidence of tricuspid valve–related reoperation was 18.2% (95% CI, 6.5%-53.9%) at 10 to 22 years after tricuspid surgery and 42.0% (95% CI, 7.4%-74.9%) at 23 years in the TVP group, whereas that was 0% at 10 to 15 years and 18.9% (95% CI, 0.8%-56.1%) at 20 years in the TVR group. There were no significant differences between the groups ($P = .1290$). *TVP*, Tricuspid valvuloplasty; *TVR*, tricuspid valve replacement.

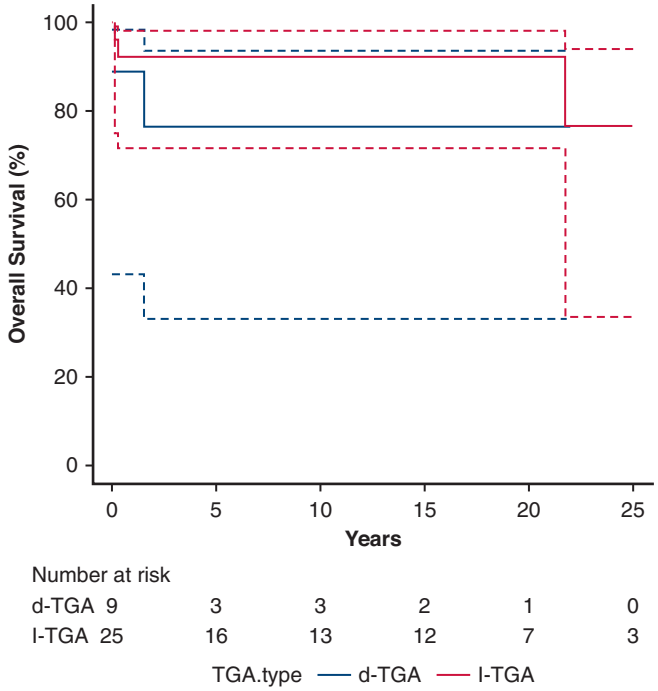


FIGURE 3. Comparison of d-TGA (*blue line*) and l-TGA (*red line*) showing overall survival. The overall survival was 76.2% ± 14.8% (95% CI, 33.2%-93.5%) at 10 to 22 years after tricuspid surgery in the d-TGA group, whereas that was 92.0% ± 5.4% (95% CI, 71.6%-97.9%) at 10 to 20 years and 76.7% ± 14.7% (95% CI, 33.5%-93.8%) at 25 years in the l-TGA group ($P = .3107$). *TGA*, Transposition of the great arteries; *d-TGA*, dextro-transposition of the great arteries; *l-TGA*, levo-transposition of the great arteries.

DISCUSSION

The systemic RV is frequently associated with late progressive TR, declining RV function, and consequently a high incidence of adverse outcomes due to congestive heart failure and eventually decreased survival.[1-5] In the previous studies, TVP provided poor results of a high incidence of recurrent TR, and TVR was advocated despite a high operative risk.[7] In our study, we reviewed the surgical outcomes of tricuspid surgery in patients with systemic RV and compared the outcomes between TVP and TVR, as well as a comparison of d-TGA and l-TGA. Figure 4 shows a graphical abstract of the study.

Survival

RV function and TR are key determinants of clinical status and long-term outcomes, especially in patients with systemic RV. In addition, a preoperative low ejection fraction below 40% and a large end-diastolic dimension were reported to be a predictor of postoperative mortality in TVR for patients with l-TGA.[8-10] Although there are few studies regarding RV function and TR in patients with patients with d-TGA undergoing the atrial switch operation, a large follow-up study on 468 atrial switch operations in Sweden and Denmark[5] concluded that long-term survival in these patients is primarily determined by tricuspid valve and RV factors, not the timing or type of surgery in childhood. In our study, of 4 late mortalities, 3 patients died of heart failure or sudden death and 2 of these 3 patients had postoperative significant recurrent TR, suggesting that significant TR might have a relationship with late mortality. The TVP group, which had a higher incidence of postoperative significant recurrent TR, had significantly lower survival compared with the TVR group. Although we could not identify a potential factor of late mortality because of the small number of patients, a good late outcome might be obtained from a favorable control of TR.

Tricuspid Surgery

Tricuspid surgery is an exclusive measure to improve TR and maintain RV function. Recent several studies proved that tricuspid surgery in the early stage of RV dysfunction could bring favorable short- and long-term outcomes.[7,8,11,12] As tricuspid surgery, TVP is not generally recommended because of previous unsatisfactory outcomes, such as a high incidence of recurrent TR in patients with systemic RV dysfunction, whereas TVR was advocated despite a high operative risk.[7,10-14] Certainly, TVR seems to have some operative risks because longer aortic crossclamp time and 2 bleeding events were found in the TVR group of our study; however, there was no early mortality in the TVR group.

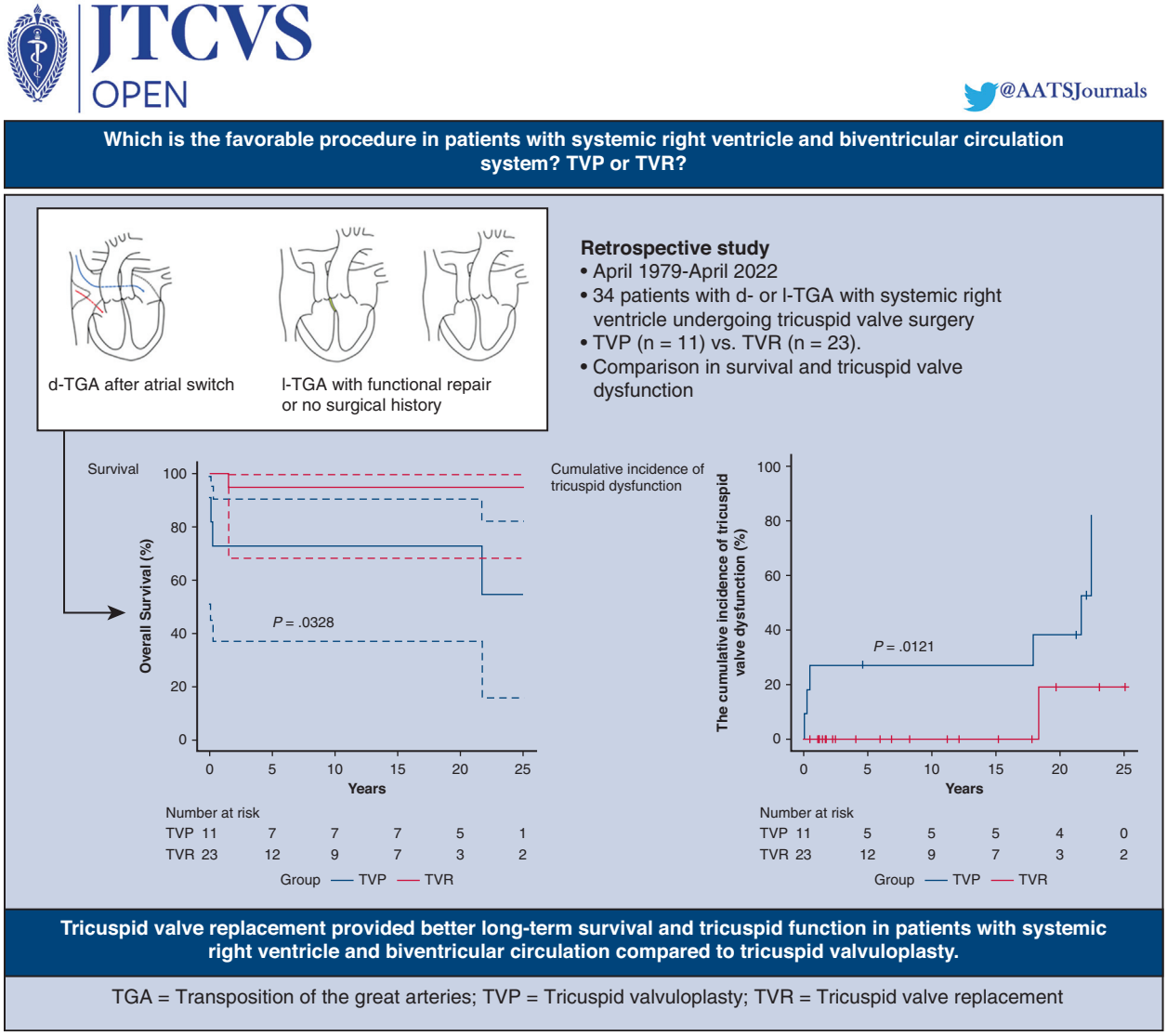


FIGURE 4. Summary of the study. A total of 34 patients with d-TGA or l-TGA with biventricular circulation and systemic RV were divided into 2 groups based on the tricuspid procedure: TVP (n = 11) and TVR (n = 23). There were significant differences between the groups in survival and freedom from tricuspid valve dysfunction. *TVP*, Tricuspid valvuloplasty; *TVR*, tricuspid valve replacement; *d-TGA*, dextro-transposition of the great arteries; *l-TGA*, levo-transposition of the great arteries.

Although the cumulative incidence of tricuspid valve–related reoperation was not significantly different between the groups, the cumulative incidence of tricuspid valve dysfunction was significantly higher in the TVP group in our study. In the TVP group, 6 patients experienced significant TR: Two patients eventually died of heart failure (1 of 2 underwent TVR), 2 patients underwent TVR, and 2 patients are outpatients with significant TR. Thus, more than half of the TVP group seemed to be associated with significant recurrent TR. Similar results were seen in the report by Deng and colleagues,[10] where recurrent TR, defined as above mild degree, was observed in 60% of patients undergoing TVP. TVP is challenging in some patients with systemic RV due to tethering and plastering. More than mild tethering seems to predict a high rate of residual TR[15] and might be a reason to replace a valve because this cannot be treated with annuloplasty alone. Ebstein-like tricuspid dysplasia such as plastering is occasionally found in patients with l-TGA and makes it more difficult to complete TVP. Myers and colleagues[16] reviewed TVP in younger groups with l-TGA with Ebstein-like dysplasia of tricuspid valve undergoing anatomic repair and concluded that valvuloplasty should be considered for significant TR associated with Ebstein-like dysplasia. However, because this report included the tricuspid valve in the pulmonary RV, the same outcomes might not be applied

to patients with systemic RV. In our study, TVP was performed in only 1 patient with Ebstein-like tricuspid dysplasia; however, the patient underwent TVR 1 month after TVP. In recent years, we have performed TVR in patients with systemic RV and Ebstein-like tricuspid dysplasia.

Comparison of Dextro-Transposition of the Great Arteries and Levo-Transposition of the Great Arteries

Because underlying pathological mechanisms between d-TGA and l-TGA are not basically the same, the postoperative course including RV function and the mode of TR also seem to be different. Previous studies showed that the clinical course of d-TGA and l-TGA showed similarities in RV dysfunction and the mode of TR, although most studies focused on 1 group, making an accurate comparison difficult.[14,17-19] Morcos and colleagues[19] showed that l-TGA and d-TGA patients had similar RV size and shape, whereas global RV function was lower in d-TGA than l-TGA using ejection fraction and normalized tricuspid annular systolic plane excursion. In our study, the preoperative ejection fraction of the RV by angiography was significantly lower in the d-TGA group, whereas the postoperative RV size was significantly larger in the l-TGA group compared with the d-TGA group, and the postoperative RV function was similar between the groups. Because both groups have a small number of patients making bias in comparison, more patients and further studies will be required. Regarding survival and recurrence of TR, Koolbergen and colleagues[14] compared l-TGA and d-TGA patients and showed no difference in the composite end point of survival or recurrence of TR. Our study also showed similar outcomes: no significant differences between d-TGA and l-TGA patients in survival and tricuspid valve-related reoperation.

Limitations

This study was a retrospective, single-center study. Because of the rarity, the number of patients was not enough for an accurate group comparison. Significant differences were identified in terms of survival and tricuspid dysfunction between the groups; however, it is necessary to validate these findings through additional studies, such as a propensity score–matched analysis conducted in a larger multicenter study. Although both d-TGA and l-TGA patients have the RV as a systemic ventricle, these pathological conditions were different. Because this was a long and wide retrospective study, our study also included bias regarding postoperative management, surgical techniques, and uncommon surgical strategies. The comparison of RV dimension and function between TVP and TVR was inaccurate because some patients in the TVP group died or underwent TVR.

CONCLUSIONS

TVR provided better long-term survival and tricuspid function in patients with systemic RV compared with TVP, and postoperative significant TR was found in more than half of the patients in the TVP group. Significant differences between d-TGA and l-TGA were found in the size of the RV, whereas there were no significant differences in survival, tricuspid function, and RV function.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

References

1. Graham TP, Bernard YD, Mellen BG, Celermajer D, Baumgartner H, Cetta F, et al. Long-term outcome in congenitally corrected transposition of the great arteries: a multi-institutional study. *J Am Coll Cardiol*. 2000;36:255-61.
2. Voskuil M, Hazekamp MG, Kroft LJM, Lubbers WJ, Ottenkamp J, van der Wall EE, et al. Postsurgical course of patients with congenitally corrected transposition of the great arteries. *Am J Cardiol*. 2015;83:558-62.
3. Bogers AJJC, Head SJ, de Jong PL, Witsenburg M, Kappetein AP. Long term follow up after surgery in congenitally corrected transposition of the great arteries with a right ventricle in the systemic circulation. *J Cardiothorac Surg*. 2010;5:74.
4. Vejlstrup N, Sørensen K, Mattsson E, Thilén U, Kvidal P, Johansson B, et al. Long-term outcome of Mustard/Senning correction for transposition of the great arteries in Sweden and Denmark clinical perspective. *Circulation*. 2015;132:633-8.
5. Broberg CS, van Dissel A, Minnier J, Aboulhosn J, Kauling RM, Ginde S, et al. Long-term outcomes after atrial switch operation for transposition of the great arteries. *J Am Coll Cardiol*. 2022;80:951-63.
6. Lange PE, Onnasch DG, Schaupp GH, Zill C, Heintzen PH. Size and function of the human left and right ventricles during growth. Normative angiographic data. *Pediatr Cardiol*. 1982;3:205-11.
7. Scherptong RW, Vliegen HW, Winter MM, Holman ER, Mulder BJ, van der Wall EE, et al. Tricuspid valve surgery in adults with a dysfunctional systemic right ventricle: repair or replace? *Circulation*. 2009;119:1467-72.
8. Mongeon FP, Connolly HM, Dearani JA, Li Z, Warnes CA. Congenitally corrected transposition of the great arteries ventricular function at the time of systemic atrioventricular valve replacement predicts long-term ventricular function. *J Am Coll Cardiol*. 2011;57:2008-17.
9. van Son JA, Danielson GK, Huhta JC, Warnes CA, Edwards WD, Schaff HV, et al. Late results of systemic atrioventricular valve replacement in corrected transposition. *J Thorac Cardiovasc Surg*. 1995;109:642-52; discussion 652-3.
10. Deng L, Xu J, Tang Y, Sun H, Liu S, Song Y. Long-term outcomes of tricuspid valve surgery in patients with congenitally corrected transposition of the great arteries. *J Am Heart Assoc*. 2018;7:e008127.
11. Prieto LR, Hordof AJ, Secic M, Rosenbaum MS, Gersony WM. Progressive tricuspid valve disease in patients with congenitally corrected transposition of the great arteries. *Circulation*. 1998;98:997-1005.
12. Kral Kollars CA, Gelehrter S, Bove EL, Ensing G. Effects of morphologic left ventricular pressure on right ventricular geometry and tricuspid valve regurgitation in patients with congenitally corrected transposition of the great arteries. *Am J Cardiol*. 2010;105:735-9.
13. Said SM, Dearani JA, Burkhart HM, Connolly HM, Eidem B, Stensrud PE, et al. Management of tricuspid regurgitation in congenital heart disease: is survival better with valve repair? *J Thorac Cardiovasc Surg*. 2014;147:412-7.
14. Koolbergen DR, Ahmed Y, Bouma BJ, Scherptong RW, Bruggemans EF, Vliegen HW, et al. Follow-up after tricuspid valve surgery in adult patients with systemic right ventricles. *Eur J Cardiothorac Surg*. 2016;50:456-63.

15. Fukuda S, Song JM, Gillinov AM, McCarthy PM, Daimon M, Kongsaerepong V, et al. Tricuspid valve tethering predicts residual tricuspid regurgitation after tricuspid annuloplasty. *Circulation*. 2005;111:975-9.
16. Myers PO, Bautista-Hernandez V, Baird CW, Emani SM, Marx GR, del Nido PJ. Tricuspid regurgitation or Ebsteinoid dysplasia of the tricuspid valve in congenitally corrected transposition: is valvuloplasty necessary at anatomic repair? *J Thorac Cardiovasc Surg*. 2014;147:576-80.
17. Sim M-M. Adaptation of the systemic right ventricle in a congenitally corrected transposition of the great arteries. *Circulation*. 2013;127:e448-50.
18. Pettersen E, Helle-Valle T, Edvardsen T, Lindberg H, Smith HJ, Smevik B, et al. Contraction pattern of the systemic right ventricle. Shift from longitudinal to circumferential shortening and absent global ventricular torsion. *J Am Coll Cardiol*. 2007;49:2450-6.
19. Morcos M, Kilner PJ, Sahn DJ, Litt HI, Valsangiacomo-Buechel ER, Sheehan FH. Comparison of systemic right ventricular function in transposition of the great arteries after atrial switch and congenitally corrected transposition of the great arteries. *Int J Cardiovasc Imaging*. 2017;33:1993-2001.

Key Words: systemic right ventricle, tricuspid valve regurgitation, tricuspid valve surgery, transposition of the great arteries

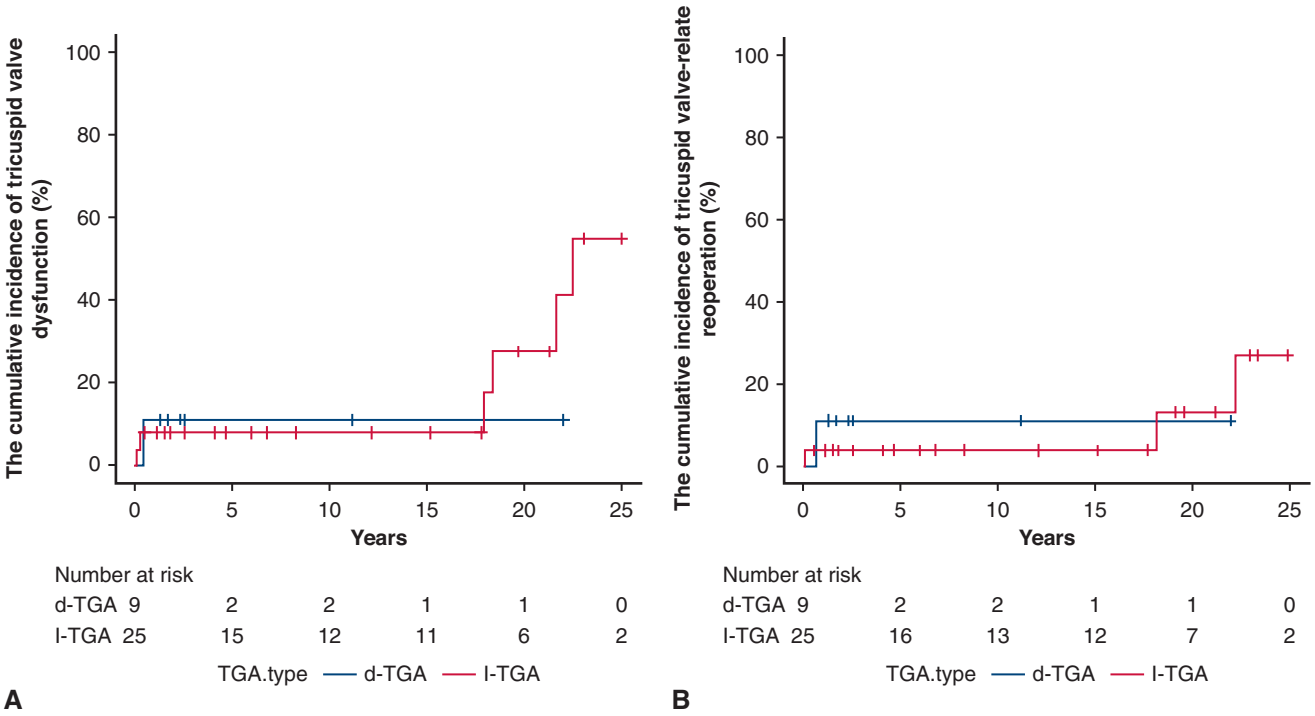


FIGURE E1. Comparison of d-TGA (*blue line*) and l-TGA (*red line*) showing (A) cumulative incidence of tricuspid dysfunction and (B) cumulative incidence of tricuspid valve–related reoperation. A, The cumulative incidence of tricuspid dysfunction was 11.1% (95% CI, 0.6%-38.8%) at 10 to 20 years after tricuspid surgery in the d-TGA group, whereas that was 8.0% (95% CI, 1.4%-22.5%) at 10 to 15 years after tricuspid surgery, 27.6% (95% CI, 7.2%-53.2%) at 20 years, and 54.9% (95% CI, 19.2%-80.5%) at 25 years in the l-TGA group. There were no significant differences between the groups ($P = .7650$). B, The cumulative incidence of tricuspid valve–related reoperation was 11.1% (95% CI, 0.6%-38.8%) at 10 to 20 years after tricuspid surgery in the d-TGA group, whereas that was 4.0% (95% CI, 0.3%-17.0%) at 15 years after tricuspid surgery, 13.2% (95% CI, 1.8%-36.3%) at 20 years, and 27.0% (95% CI, 5.0%-56.3%) at 25 years in the l-TGA group. There were no significant differences between the groups ($P = .6346$). *TGA*, Transposition of the great arteries; *d-TGA*, dextro-transposition of the great arteries; *l-TGA*, levo-transposition of the great arteries.

TABLE E1. Characteristics of patients with dextro-transposition of the great arteries and levo-transposition of the great arteries

Variable	d-TGA	l-TGA	*P* value
Patient number, n	11	23	
Age (y)	33 (10-36)	23 (15-32)	.6563
Male, n (%)	5 (45%)	15 (65%)	1.0000
Body weight (kg)	53.3 ± 16.3	44.7 ± 18.2	.2844
Without history of cardiac surgery	0 (0%)	17 (74%)	.0009
Time from the functional repair (y)	14.8 (7.3-22.6)	23.8 (11.7-35.3)	.3361
Comorbidity			
Hypertension	2 (18%)	6 (26%)	.1648
Dyslipidemia	0 (0%)	0 (0%)	—
Hyperuricemia	1 (9%)	2 (9%)	.5488
Chronic renal failure (creatinine > 2 mg/dL)	0 (0%)	0 (0%)	—
Cerebrovascular disease	1 (9%)	0 (0%)	.2467
Arrhythmia	5 (45%)	13 (57%)	1.0000
Ebstein-like tricuspid dysplasia	0 (0%)	5 (22%)	.2933
Tricuspid valve regurgitation			
Mild-moderate	1 (9%)	0 (0%)	.2467
Moderate	4 (36%)	9 (39%)	.7041
Severe	6 (55%)	14 (61%)	1.0000
Catheter study			
Right ventricular end-diastolic volume (% of normal)	121 (108-145)	139 (121-190)	.2340
Right ventricular ejection fraction	42.7 (40.6-46.0)	47.4 (45.3-57.0)	.0254
Cardiac index	2.7 (2.5-2.9)	2.9 (2.5-3.1)	.7383

d-TGA, Dextro-transposition of the great arteries; *l-TGA*, levo-transposition of the great arteries.